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A Comparative Study of Mosul and Haditha Dams, Iraq: Geological Conditions

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Abstract

Mosul and Haditha Dams are the largest dams on the Tigris and Euphrates Rivers in Iraq, respectively. Both dams are of earthfill type and constructed on sedimentary rocks, but have different geological conditions. Both of them suffer from karstification problems. The former; however, suffers from intense karstification, which has endangered the stability of the dam and possible failure.
The karstification in both sites is of different origins, types, shapes, sizes and depths, as well as in different rocks and geological formations. In Mosul Dam site, the highly dissolved gypsum beds of the Fatha Formation has formed solution type sinkholes with cavities of different shapes and sizes at different depth; attaining to about 250 m upon which the foundations of the dam are located. In Haditha Dam site, the karstification occur in the limestone beds of the Euphrates Formation, the developed sinkholes are of collapse type with regular shapes; either circular or oval apertures. The thickness of the karstified sequence in the foundations is not more 50 m.
This research work is to highlight the role of the geological conditions, especially when the karstification in the safety of both dams is concerned and its effect on the foundations of the dams

Keywords: Mosul Dam; Haditha Dam; Dam site geology; Karstification, Gypsum and Limestone beds.

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1 Introduction

Mosul and Haditha Dams are the two largest dams of Iraq, whether according to the volume of materials used in their construction or the volume of their storage. They impound the Tigris and Euphrates Rivers, respectively.
The two dams were constructed during the eighties of the last century although the investigation works and studies had taken much of the fifties, sixties and the seventies. Mosul Dam is located at 42° 13´ Longitude and 36° 37´ Latitude at a distance of 70 km northwest of Mosul city, which is about 400 kilometers north of the capital Baghdad. Haditha Dam is located at 34° 12´ Latitude and 42° 21´ Longitude, about 8 km northwest of Haditha town, which is about 270 kilometers northwest of Baghdad (Figure 1).

The two dams share together many similarities. In both dam sites karsts are present, but the karst forms; however, are of different characteristics and origin, which result in different approaches towards foundation treatment.
This paper seeks to highlight the important topics involved and to present a comparative study of the geology of the two dams with emphasis on the role of the karstification on the foundations of the two dams and their effect on their stability. Moreover, to highlight the failure possibility of Mosul dam; in spite of the enormous attempts of grouting that were carried out since the first year of the construction which still continues as an ongoing process.

A wealth of information on both dams is available; the bulk of it is from published papers, geological reports and maps, relevant books and the accumulated experience of the authors.

The Construction of Mosul Dam was started on the 25th January 1981 and completed on 24th July 1986. Finally, at 1978 the Swiss Consultant Consortium of Zurich- Geneva was selected to produce the planning report, final design and contract documents, perform the general supervision and, share with Energoprojekt of Belgrade the daily supervision on the works. Mosul Dam is an earthfill dam with total length of 3400 m, the maximum height of the dam is 113 m from the deepest point in the river channel; accordingly, the crest level was fixed at 341.6 m (a.s.l.). Normal Operation Water level is 330 m (a.s.l.), Maximum Operation Water is 335 m (a.s.l.) and Maximum Flood Water Level is 338 m (a.s.l.). The storage capacity is 11.11×10^9 m^3 at elevation 330 m (a.s.l.) [1].

Figure 1: Location of Mosul and Haditha Dams, Iraq

The Construction of Haditha dam was begun in 1977 and it was completed in 1988. Investigation works and preparation of the general design and specifications were initiated by Soviet organizations in contracts with the Iraqi Government. Haditha Dam is an earthfill Dam with total length of 9064 m, the maximum height of the dam is 57 m from the deepest point at the river channel and dam crest level is 154.00 m (a.s.l.). The Normal Operation Water level is 143 m (a.s.l.), Maximum Operation Water is 147 m (a.s.l.) and Maximum Flood Water Level is 152.2 m (a.s.l.). The storage capacity is 6×10^9 m^3 at elevation 143 m (a.s.l.) [1].

2 Comparison of Geological Conditions

2.1. General

Mosul and Haditha Dams are located in sites of different geological conditions; although both have one common aspect that is the karstification. The karstification; however, is quite different in the two sites in many forms, the only common aspect is that in both sites the karstification is an active process and it is still ongoing.

The main geological conditions in both Mosul and Haditha Dams are compared to each other in order to show the main differences between the main geological aspects and indicate their effects on the stability of both dams. A very brief comparison between the main geological aspects in both dams is presented in Table (1).

The main geological aspects; geomorphology, tectonics and structural geology and stratigraphy of the two main dams are described; systematically. The used data is based mainly on the published maps and reports by Iraq Geological Survey (GEOSURV); however, other published data is used too when needed. The systematic description style is chosen to enable easier comparison between the dams; whenever a certain geological aspect is concerned. Those aspects, which are more significant; as far as the dam safety is concerned, are emphasized more; such as the origin of the karstification, features, forms, sizes, reasons, type of the rocks and geological formations, as well as the age of the karstification.

2.2. Geomorphology

The main geomorphological units and features of Mosul and Haditha dams are described in details; hereinafter.

2.2.1. Geomorphology of Mosul Dam

Mosul Dam and the reservoir area are located; physiographically within the Low Mountainous Province [2]. It is characterized by hilly terrain that rises to low mountainous area. The mountains form anticlines, which trend mainly in NW – SE direction and change~~s~~ westwards almost to E – W direction.

A) Geomorphological Units: The main geomorphological units and forms in the area under consideration belong to the following origins:

Structural – Denudational Origin: The main units are the anticlinal ridges, which form the limbs of the existing anticlines formed either by limestone, and/ or gypsum of the Fatha Formation (Figure 2). Another geomorphological form is the flat irons formed either in limestone and/ or gypsum beds (Figure 2); however, in the outer areas of the limbs, sandstone beds of the Injana Formation form cuestas and hogbags; due to their alternation with soft claystone beds [3, 4].

Table 1: Brief comparison between the main geological aspects at both Mosul and Haditha Dam sites

Aspects	Mosul Dam	Haditha Dam	Remarks
Tectonic And Structural Characters	Within the Low Folded Zone of the Outer Platform. The dam is located in the plunge of Butma East anticline.	Within the Inner Platform. The dam is located in an unfolded area; therefore, the beds are almost horizontal.	Both dams are located; tectonically, within the Arabian Plate.
Geomorphological Aspects	Anticlinal ridges, karst forms, flat irons and intensive weathering.	Residual soil, Karst forms, moderate to intensive weathering.	The only common feature is the karst forms
Stratigraphy and Type of the rocks	The dam site is within the Fatha Formation, which consists of cyclic sediments, each cycle includes marl, limestone and gypsum.	The dam site is within the Euphrates Formation, which consists of basal conglomerate, hard dolomite, chalky limestone and undulated limestone.	Both dams are located within sedimentary rocks sequence; almost all rocks are highly karstified.
Karstification	The main karst form is the sinkholes, majority of them are within the gypsum beds. The sinkholes are of solution type. The thickness of the karstified rocks is about 300 m.	The main karst form is the sinkholes, majority of them are within the limestone beds. The sinkholes are of collapse type. The thickness of the karstified rocks is about 50 m.	The karstification is an active process and still ongoing.

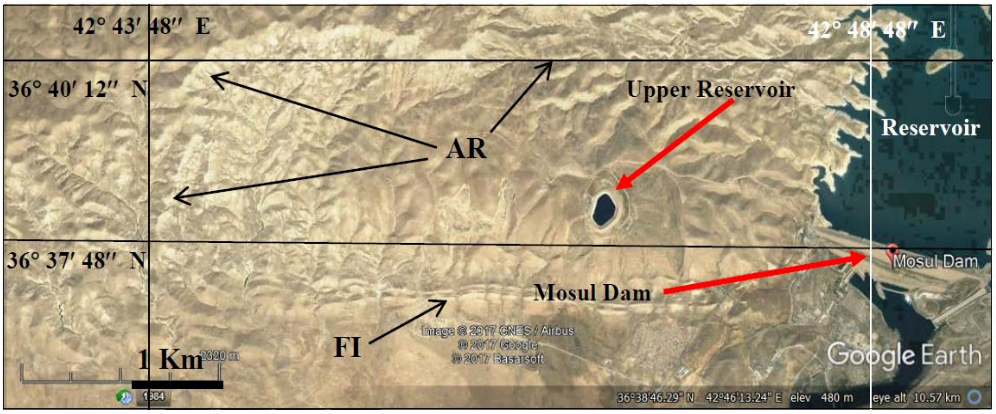

Figure 2: Google Earth image of Mosul Dam site. Note the anticlinal ridges (**AR**) and the Flat irons (**FI**)

Alluvial Origin: Two main units are developed. **1)** River terraces consisting of gravels of different rock types, sizes and shapes, cemented by gypsiferous material; usually (3 – 4) levels are developed, the thickness of each level varies from (5 – 8) m. **2)** Flood plain consisting of sand, silt and clay; usually two levels are developed. The thickness of each level varies from (1.5 – 3) m.

Karst Origin: Sinkholes are the most common karst forms in the dam site and reservoir area. They are described latter on separately.

B) Weathering and Erosion: The following weathering and erosion types are acting in the area under consideration.

Chemical Weathering: Is more effective and common; as indicated by the presence of solution sinkholes formed mainly in gypsum beds.

Mechanical (Physical) Weathering: Is less active; as can be seen on the weathering grade of the rocks, especially the hard limestone and dolomite beds within the Fatha Formation, which are slightly weathered, whereas the soft rocks like claystone and marl of the Fatha and Injana formations are moderately to highly weathered.

Rill Erosion: Is the most common erosion type; as can be seen on the slopes of soft to moderately hard rocks.

Gulley Erosion: Is usually acting in deeply incised valleys, especially in meandering of the valley courses.

Sheet Erosion: Is the less abundant type and acting on almost flat areas, which are very rare in the concerned area.

C) Mass Movements: The most common types are:

Toppling: This is the most abundant phenomenon, where the alternation of hard and soft rocks exhibit toppling of blocks of the hard rocks, which are underlain by soft rocks, such as sandstone overlying claystone (Injana Formation), limestone and gypsum underlain by marl and/ or claystone (Fatha Formation).

Landslides: These are very rare phenomena, especially along the banks of Mosul Lake. The sizes are small with no significant effect on the stability of the slopes.
Mud Flows: These are very rare phenomena developed within claystone beds of the Fatha and Injana formations, especially along steep slopes.

2.2.2. Geomorphology of Haditha Dam

Haditha Dam and the reservoir area are located; physiographically within the Western Desert and Al-Jazira Provinces [2]. Both provinces are characterized by flat terrain dissected by large valleys, especially the former province (Figure 3).

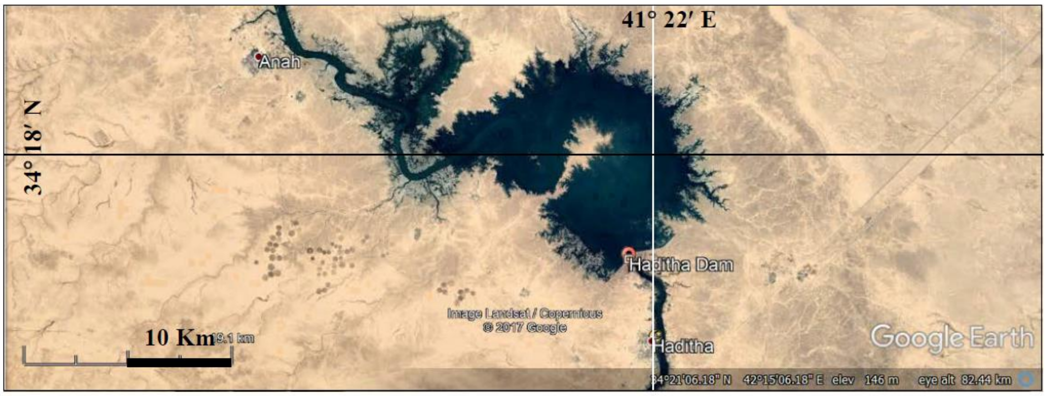

Figure 3: Google Earth image of Haditha Dam and lake. Note the flat terrain and large valleys; south of the lake

A) Geomorphological Units: The main geomorphological units and forms in the area under consideration area belong to the following origins [5]:

Alluvial Origin: Two main units are developed. **1)** River terraces consisting of gravel of different rock types, sizes and shapes cemented by sandy and clayey materials and rarely gypsiferous, especially those north of the river. Usually (2 – 3) levels are developed, the thickness of each level varies from (3 – 5) m. **2)** Flood plain consist of sand, silt and clay; usually two levels are developed. The thickness of each level varies from (1.5 – 3) m.
Karst Origin: Sinkholes are the most common karst forms in the dam site and reservoir area. They are described latter on separately.

B) Weathering and Erosion: The following weathering and erosion types are acting in the concerned area.
Chemical Weathering: Is more effective and common; as indicated by the presence of sinkholes formed in limestone beds.
Mechanical (Physical) Weathering: Is less active; as can be seen on the weathering grade of the rocks, especially the hard limestone and dolomite beds of the Euphrates Formation, which are slightly weathered, whereas the soft rocks like claystone and marl are of the Fatha and Nfayil formations are moderately to highly weathered.

Sheet Erosion: Is the more abundant type and acting on almost flat areas, which are very common in the area, especially south of the river.
Rill Erosion: Is the less abundant erosion type; as can be seen on the slopes of soft to moderately hard rocks.
Gulley Erosion: Is usually acting in deeply incised valleys, especially in meandering of the valley courses.

C) Mass Movements: The most common types are:
Toppling: This is the most abundant phenomenon, where the alternation of hard and soft rocks exhibit toppling of blocks of the hard rocks, which are underlain by soft rocks, such as limestone and dolomite overlying claystone (Euphrates and Nfayil formations), limestone and gypsum underlain by marl and/ or claystone (Fatha Formation).
Mud Flows: These are also very rare phenomena developed within claystone beds of the Fatha Formation, especially along steep slopes.

2.3. Tectonics and Structural Geology

The main structural features of the both Mosul and Haditha dams and tectonic zones are described in details; hereinafter.

2.3.1. Mosul Dam

Mosul Dam site and reservoir area are located within the Cham-Chamal Subzone of the Low Folded Zone; within the Unstable Shelf of the Arabian Plate [6]. The updated tectonic framework of Iraq [7]; however, has considered that the dam site and reservoir area are located within the Low Folded Zone, within the Outer Platform of the Arabian Plate, all belong to the Zagros Thrust – Fold Belt.

The Low Folded Zone of Iraq is characterized by long and narrow anticlines; mainly with exposed Miocene rocks in their cores, and wide and deep synclines, which are usually filled with Quaternary sediments. Mosul Dam is located within Butma East anticline, which has almost E – W trend with steeper southern limb (Figure 2).

Many anticlines surround the reservoir area of Mosul Dam and many others are located nearby to the reservoir and the dam site. Some of them exhibit strange shapes and local dislocations due to a major deep seated fault called Sasan – Bekhair Fault [7] (Figure 4), which passes NW of the dam with clear dislocation of the axes and beds of many anticlines (Figure 4). Moreover, many other small faults of different types and different dislocations were mapped in the dam site and reservoir area [8]. It is worth mentioning that all structural disturbances have no any significant effect on the dam, since there is no any evidence of neotectonic activity.

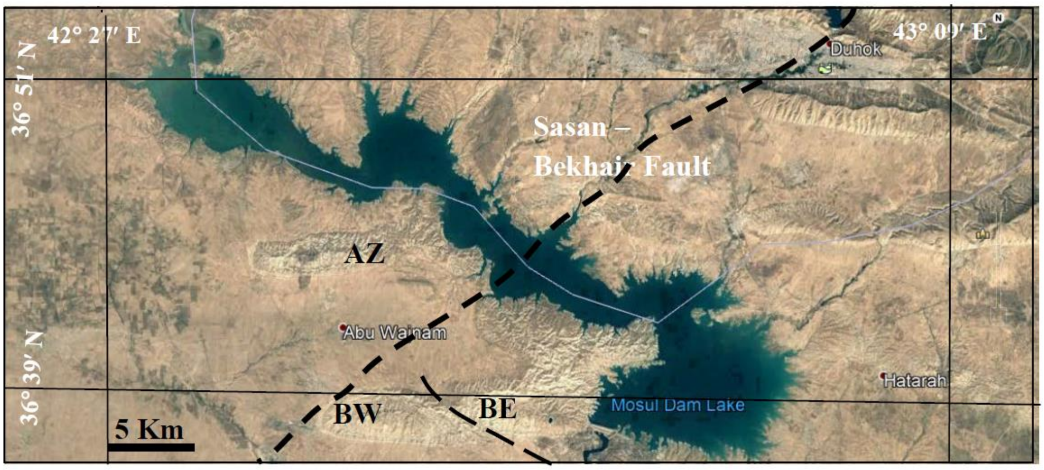

Figure 4: Google Earth image of Mosul Dam and Lake. Note the deep seated Sasan – Bekhair Fault. Anticlines: BE = Butma East, BW = Butma West, AZ = Ain Zala,

2.3.2. Haditha Dam

Haditha Dam site and reservoir area are located within two different tectonic zones. The northern part of the dam (left abutment) and reservoir belongs to the Jazira Zone within the Mesopotamia Foredeep of the Outer Platform. The southern part of the dam (right abutment) and reservoir; however, belongs to the Western Desert Zone of the Inner Platform. Both Outer and Inner Platforms belong to the Arabian Plate [7].

The Jazira Zone of Iraq is characterized by the absence of surface structural features; however, many subsurface anticlines exist; all are originally inverted grabens. Nevertheless, the area is rich in Neotectonic evidences [9]. All those structural features have no significant effect on the stability of the dam.

The Western Desert Zone of Iraq is characterized by tectonic rest as evidenced from the absence of any structural features; apart from Anah anticline, which is far from the dam site (Figure 5). Neotectonic evidences; however, are present in different parts in different forms, but not near the dam site [10, 11]. However, some structurally controlled straight fine branches of valleys, which are oriented in WNW – ESE trend west of the dam (Figure 5) indicate neotectonic evidence [12].

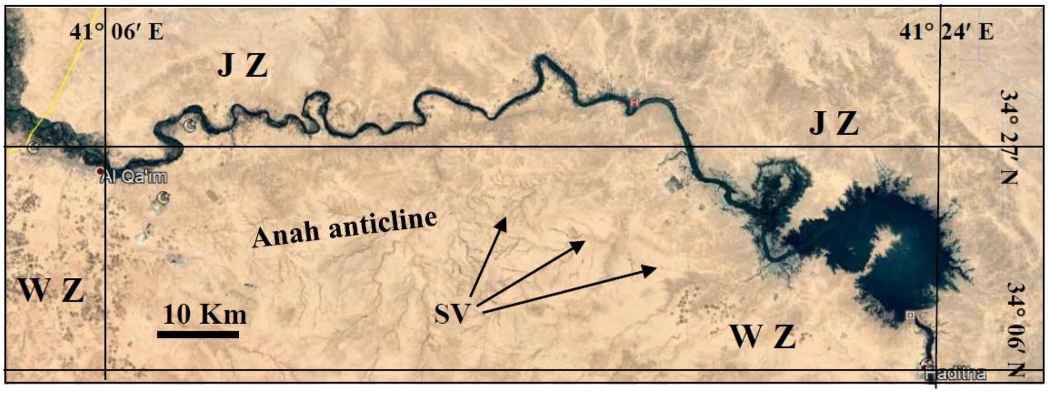

Figure 5: Google Earth image showing regional tectonic frame work of Haditha Dam site. JZ = Jazira Zone, WZ = Western Desert Zone, SV = Straight valleys

2.4. Stratigraphy

The main lithological constituents of the exposed geological formations at both Mosul and Haditha dams are described; hereinafter.

2.4.1. Mosul Dam

The exposed geological formations at Mosul Dam site and near surroundings are shown in (Figure 6). The exposed geological formations are described from the oldest to the youngest; hereinafter.

– **Pila Spi Formation** (Upper Eocene): The formation consists of well bedded and hard dolomitic limestone, dolomite and limestone. The formation exposed far from the dam site (Figure 6).

– **Euphrates Formation** (Lower Miocene): The formation consists of well bedded and hard dolomitic limestone, dolomite and limestone. The formation is exposed east and south of the dam site (Figure 6). Part of the foundations of the dam is located on this formation, which exhibit intense karstification.

– **Fatha Formation** (Middle Miocene): The formation is divided into two members: **Lower Member**, consists of cyclic deposits, each cycle consists of green marl, limestone and gypsum. **Upper Member**, consists of cyclic deposits, each cycle consists of green marl, red claystone, limestone and gypsum. The uppermost cycles include fine reddish brown sandstone. The formation is widely exposed in the dam site and along the southern and northern banks of the reservoir (Figure 6). The foundation and abutments of the dam are located in this formation, which exhibits intense karstification, which is very active hitherto.

– **Injana Formation** (Upper Miocene): The formation consists of cyclic deposits; each cycle consists of sandstone, siltstone and claystone. All rocks are reddish brown in color. The formation is exposed along the northern bank of the reservoir (Figure 6).

– **Mukdadiya Formation** (Upper Miocene – Pliocene): The formation consists of cyclic deposits; each cycle consists of sandstone; some are pebbly, siltstone and claystone. All rocks are grey in color. The formation is exposed east of the dam site only (Figure 6).

– **Bai Hassan Formation** (Pliocene -Pleistocene): The formation consists of conglomerate beds alternated with reddish brown claystone with rare sandstone beds. The formation is exposed in a very restricted area east of the dam site only (Figure 6).

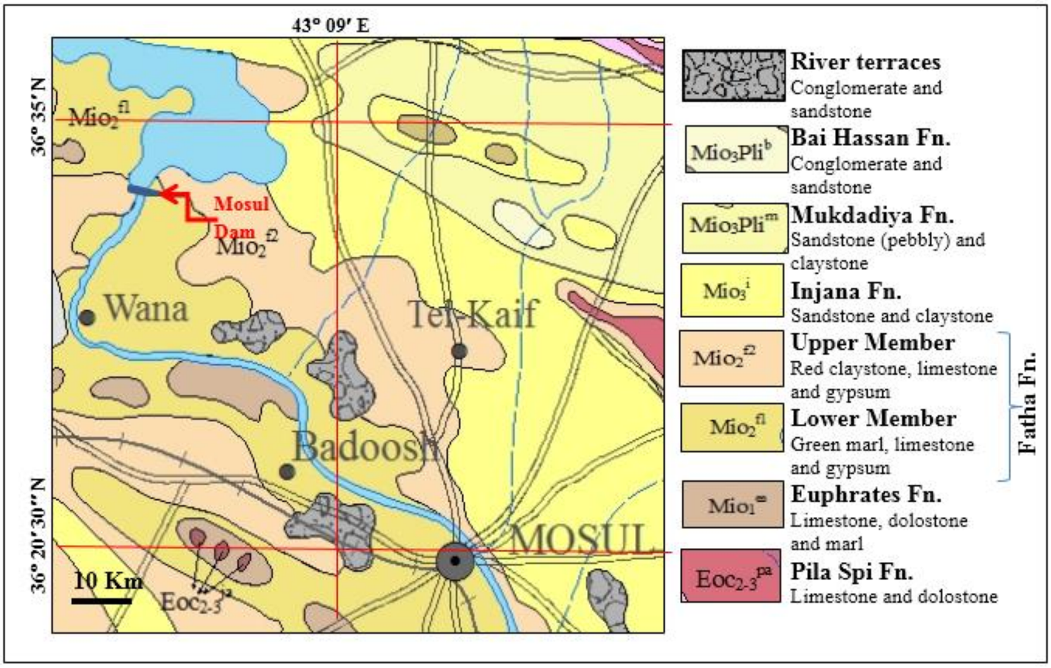

Figure 6: Geological map of Mosul Dam site and near surroundings [2]

2.4.2. Haditha Dam

The exposed geological formations at Haditha Dam site and near surroundings are shown in (Figure 7). The exposed geological formations are described from the oldest to the youngest; hereinafter.

– **Anah Formation** (Upper Oligocene): The formation consists of massively bedded and hard dolomitic limestone and cavernous limestone. The formation is exposed south of the dam site and some valleys and plays effective role in development of the sinkholes (Figure 7).

– **Euphrates Formation** (Lower Miocene): The formation consists of two members. **Lower Member** consists of basal conglomerate~~,~~ which plays a big role in water circulation and development of the sinkholes. The conglomerate is overlain by well bedded and hard dolomitic limestone, dolomite and limestone; followed by thickly bedded chalky limestone; upwards become thinly bedded. This succession forms all the flat areas in the dam site and near surroundings and all the sinkholes are developed in the succession. **Upper Member** consists of brecciated dolomite with thin marl horizons; overlain by well bedded undulated limestone. The formation is exposed in all sides of the dam site and reservoir area (Figure 7). It is worth mentioning that the Soviet Geologists working in the dam site, during the geological investigation stage have considered the undulated limestone unit as part of the Fatha Formation and it is spread over all other formations, which is not true, because it means there is a break in the deposition between Lower and Middle Miocene.

– **Fatha Formation** (Middle Miocene): The formation is divided into two members: **Lower Member**, consists of cyclic deposits, each cycle consists of green marl, limestone and gypsum. **Upper Member**, consists of cyclic deposits, each cycle consists of green marl, red claystone, limestone and gypsum. The uppermost cycles include fine reddish brown sandstone. The formation is widely exposed in the northern part of the dam site and along the northern bank of the reservoir (Figure 7). The formation is highly karstified; exhibiting solution sinkholes.

– **Nfayil Formation** (Middle Miocene): The formation consists of cyclic deposits; each cycle consists of green marl and limestone. The formation is exposed as isolated hills southwest of the dam site (Figure 7).

2.5. Karstification

Karstification is the most dangerous and effective process as far as the stability of both Mosul and Haditha dams are concerned; especially in Mosul Dam. The genesis, types and sizes of the existing karst forms at both dams are described; hereinafter.

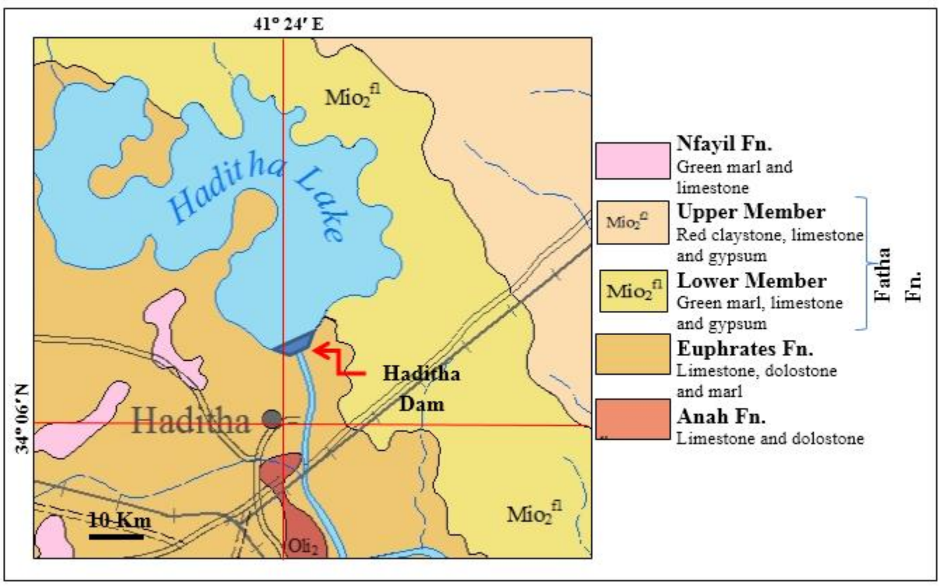

Figure 7: Geological map of Haditha Dam site and near surroundings [2]

2.5.1. Mosul Dam

The karstification is a very active process in the dam site and extends to its foundations and reservoir area [13, 14, 15, 16, 17 and 18]. The main karst feature is the sinkholes, which are developed mainly and intensively in gypsum beds and less abundant in limestone beds. Those developed in gypsum beds have irregular apertures with clear dissolving indications, the diameter of the sinkholes ranges from (< 1 – 3) m, whereas the depth rages from (< 1 – 8) m. Those developed in limestone beds have regular forms, either with circular or elliptical apertures of collapse origin, the diameter of the sinkholes ranges from (< 1 – 20) m, whereas the depth ranges from (< 1 – 15) m. The main reason of the karstification is the high dissolving ability of the gypsum beds, which increases with high static water pressure exerted by the water head in the reservoir. One more karst feature in Mosul Dam foundations are the well-developed brecciated gypsum, which are recognized in these foundations.

2.5.2. Haditha Dam

Haditha Dam site and near surroundings are a well-known karst area in Iraq [19]. A total of 54 sinkholes exist in the dam site and downstream, all are of collapse origin with circular and/ or oval shaped apertures. The diameter of the sinkholes ranges from few meter up to 110 m, whereas the depth ranges from few meters up to 55 m. Majority of the sinkholes are of active type; as indicated by the presence of many fractures of different orientations in their floors [19] and [20]. It was noticed that the main reason for the presence of dense sinkholes is the exposures of the uppermost part of the Anah Formation and the basal conglomerate of the Euphrates Formation. The basal conglomerate acts as water circulation media; both surface and groundwater; consequently, facilitating the solution of the limestone beds of the lowermost part of the Lower Member of the Euphrates Formation. Therefore, no sinkholes are developed in the Upper Member of the Euphrates Formation.

2.5.3. Comparison between Karstification in Mosul and Haditha Dams

Although both Mosul and Haditha dams suffer from karstification, but the process is quite different in both dams, as far as the genesis, size of the sinkholes, the concerned rocks and the karstification depth are concerned.

The authors believe that the karstification process in Mosul Dam is more active than that in Haditha Dam. This is confirmed by the continuous grouting of the foundations in Mosul dam to stop dissolution of the gypsum rocks, but all these attempts are in vain hitherto. The severe and active karstification in Mosul Dam as compared to that at Haditha Dam is attributed to the following reasons: **1)** The main karstified rocks at Mosul Dam are gypsum beds, which belong to the Fatha Formation, whereas at Haditha Dam the karstified rocks are limestone beds, which belong to the Euphrates Formation, **2)** The thickness of the Fatha Formation at Mosul Dam is about 300 m, whereas the thickness of the Euphrates Formation at Haditha Dam is about 50 m, **3)** The karstified gypsum rocks exist through the whole Fatha Formation (Figure 8), whereas the karstified limestone beds exist only in the Lower Member of the Euphrates Formation (Figure 9), **4)** The gypsum beds in the Fatha Formation are overlain by soft marl, which are easily disintegrated and washed out in the developed caverns in gypsum beds; accordingly accelerating the junction of caverns developed in different gypsum beds that occur in different levels (Figure 8). Whereas, in the Euphrates Formation, the karstified limestone beds are either not overlain by rocks; due to the weathering of the Upper Member of the formation or are overlain by thick (not less than 30 m) massive limestone and dolomite beds, **5)** The dissolution ability of anhydrite and gypsum beds is higher than those of limestone and dolomite beds; therefore, the developed cavities and caverns due to solution are larger in size, deeper in extent and more frequent, **6)** The water in the reservoir of Mosul Dam is sulphatic; due to the intensive exposures of the gypsum beds of the Fatha Formation (Figure 6); accordingly, the sulphatic water has more dissolving ability than the carbonate water in the reservoir of Haditha Dam, where the majority of rocks surrounding the reservoir are carbonates (Figure 7). However, the surface water, which flows from the Jazira area towards the reservoir of Haditha Dam is also sulphatic due to the exposures of the gypsum beds of the Fatha Formation in the Jazira area (Figure 7), but still the percentage of the dissolved sulphates in the water of Mosul Dam reservoir is higher than that dissolved in the water of Haditha Dam reservoir, **7)** Although the number of the developed sinkholes at Haditha Dam site and near surroundings is higher than those at Mosul Dam site, but the karstification is more active and intensive; because the whole succession (About 300 m) at Mosul Dam site is karstified, while the karstified succession in Haditha Dam is not more than (25 – 45) m, **8)** The basal conglomerate, which exists between the Anah and Euphrates formations (Figure 9), is the main reason for the karstification. Wherever it is exposed (usually in valleys), then there is a high concentration of sinkholes. This is attributed to the high porosity and permeability of the basal conglomerate; moreover, it is underlain by the cavernous rocks of the Anah Formation; therefore, both units accelerate water circulation; consequently, accelerates and facilitates the solution of the rocks of the Euphrates Formation in Haditha Dam site. In Mosul Dam, the reason of the active karstification is the cyclic nature of the Fatha Formation [3]. Each gypsum bed is underlain by limestone bed and overlain by marl and claystone. Since the marl and claystone beds are impervious~~;~~ but weak; therefore, are easily disintegrated and washed out filling the caverns developed in the dissolved gypsum beds. This is why the karstified gypsum beds appear also as brecciated gypsum.

3 Conclusions

From the reviewed and presented data in this paper, we have the following conclusions:

The geology of the two sites played most important role in the selection of the type and details of foundations' treatments; more successfully in Haditha Dam than in Mosul Dam. While both sites suffer from the presence of karsts; these karsts are of different origins, types, shapes, sizes and depths. In Mosul Dam site, it is of solution type, which was formed as a result of the high dissolution rates of gypsum beds within the foundations.

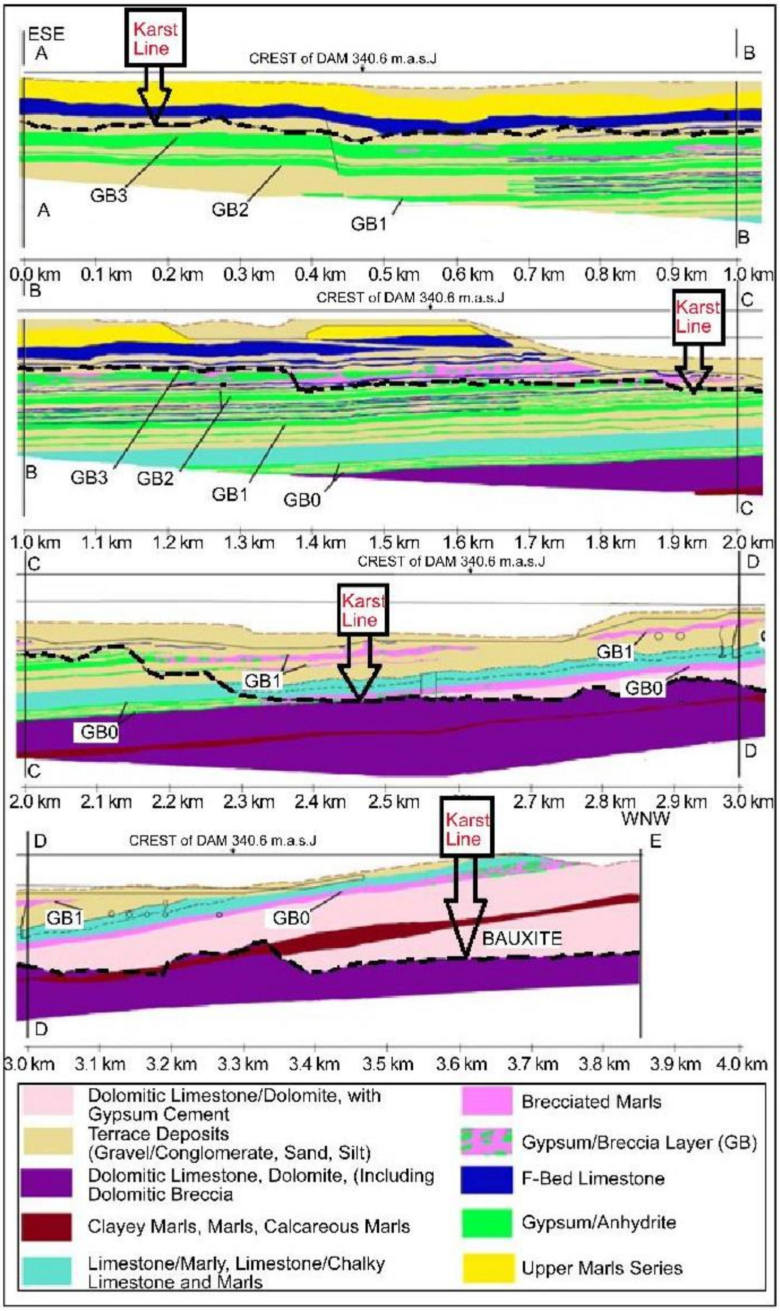

Figure 8: Assumed Karsts line in Mosul Dam foundations (From [1])

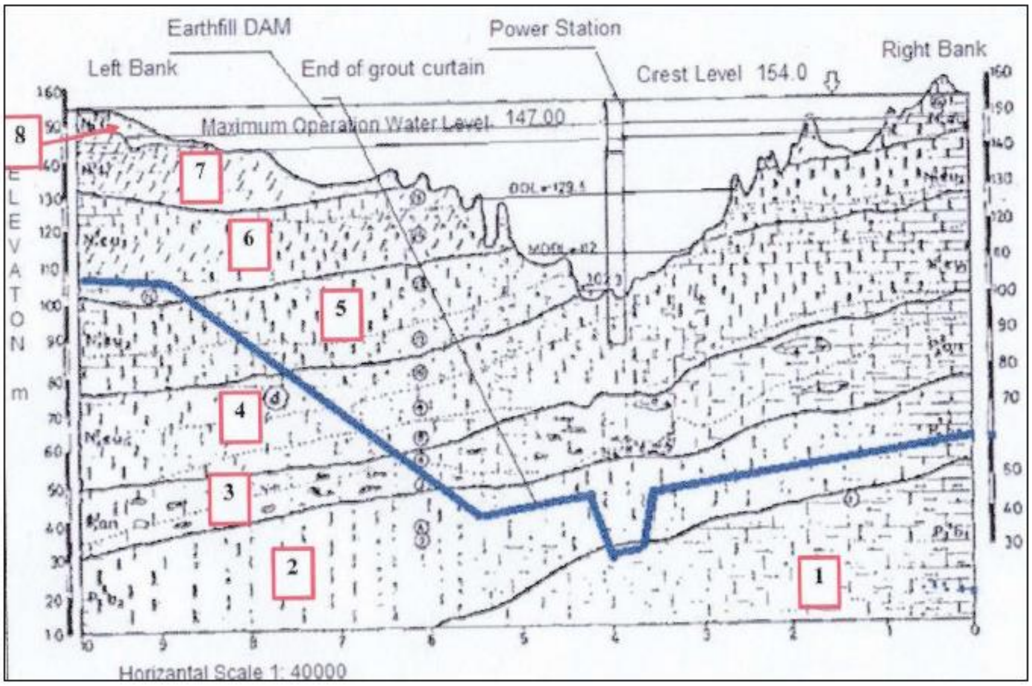

Figure 9: Geological cross section under Haditha Dam, showing the lower limits of the grout curtain. Note that the karstification is developed in the Lower Member of the Euphrates Formation (Units 3, 4 and 5), underlain by the cavernous Anah Formation (Unit 2).

In Haditha Dam site, it occurs in varying degrees in the limestone beds of the Euphrates Formations in the shape of fissures, cracks and nearly isolated sinkholes in the whole rock sequence in the foundations. Sinkholes in Mosul Dam site are of the very active and severely dissolution type, not like those in Haditha Dam site, which are of collapse type and less dangerous due to the fact that limestone is less soluble than gypsum.

The thickness of the karstified rocks in Mosul Dam site is about 300 m, whereas at Haditha Dam site is about 50 m. This large difference in the thickness of the karstified succession of the rocks also played a big role in destabilizing of Mosul Dam.

In Mosul Dam site, the rocks are tilted and deformed due to tectonic activities, which had increased the dissolution ability, whereas in Haditha Dam site, the beds are almost horizontal and not deformed; as they are not affected by tectonic forces.

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